



A fuzzy cognitive maps decision support system for renewables local planning

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ABSTRACT

Initiatives as the Covenant of Mayors and the European Union (EU) binding targets of 20-20-20 are bringing Regional Planning of Renewable Energy Sources (RES) at the center of attention nowadays. This situation creates the need for simplified and straight forward decision support systems for local governance officers. This paper presents the design and implementation of a fuzzy cognitive maps (FCM) decision support toolkit (DST) for local RES planning. DST provides the decision maker with an overall qualitative evaluation of the examined investment promptly with minimum effort. All the related parameters (legal/regulative/administrative, financial, technical, social and environmental) that affect the evaluation of RES investment in a local community are investigated. A tool based on fuzzy cognitive maps is designed and implemented on a web platform. The DST has been tested and validated successfully through application in real investments on Crete Island and comparison to the evaluation results reached by a panel of experts.

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Abbreviations: RES, renewable energy sources; EPDSS, energy planning decision support systems; FCM, fuzzy cognitive maps; DST, decision support toolkit (for local RES planning)

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1. Introduction

European Charter of Local Self-Government and the related regional policies [1,2], has strengthened planning at the decentralized local level. This planning has, also, taken place in the energy sector. Integrated regional energy planning is one of the most important tools that can demonstrate coherence among the objectives of economic growth, environmental protection and green energy development [3]. On top of that, it has to be noted that local authorities play an important role in renewable energy sources (RES) investments.

In parallel, initiatives as the Covenant of Mayors [4] and the European Union (EU) binding targets of 20-20-20 are bringing local planning of RES at the center of attention nowadays. Indeed, a big number of Municipalities, with the support of regions, provinces and other public authorities, go forward in compiling Sustainable Energy Action Plans and signing the Covenant of Mayors. The number of municipalities that have signed the Covenant of Mayors across Europe has exceeded 4500 (May 2013).

The participation level is different in most countries depending on the respective national policies. For example, United Kingdom's National Renewable Action Plan foresees regional development agency grants for the development on energy projects at regional level, as well as the constitution of Local Better Regulation Offices [5]. According to Greece's National Renewable Action Plan, Regional Administration Units are foreseen to be involved in approving specific aspects of licensing including environmental, archaeological, land use and forestry concerns [6].

The current environment creates the need for simplified and straight forward decision support systems and tools for local governance officers; approaches that demand minimal experience and technical knowledge by the officer and at the same time can give a comprehensive assessment of RES investments. This will simplify and speed up the relevant procedures the local governance structure follows, which in the end will lead to the facilitation of the deployment of RES investments.

A big number of software packages is available nowadays for analyzing the integration of RES into various energy systems [7]. Some of these tools can also be used in local planning applications, but still, the collection and pre-processing of input data needed demands considerable training from the part of the regional officers [8]. Five broad categories of models for energy planning decision support systems (EPDSS) appear in literature, namely input–output models [9–14], linear programming models [9], Life Cycle Assessment approaches [15], general equilibrium models which can forecast possible outcomes from various changes based on cost effectiveness analysis [9] and impact pathway approach models [16]. In addition, hybrid approaches using combined elements of the above approaches exist [9]. EPDSS models can, also, be categorized as Bottom Up (detailed end-use technology models) and Top Down (macroeconomic activity projections) [9]. Models have been proposed that are based on minimization/maximization of an objective function, as well as models based on simulation and optimization approaches [17,18]. Optimization of simulations approaches are also found in literature, but usually applied in smaller areas [19]. Scenario planning is also another tool that finds frequent application in various EPDSS approaches. Multi-criteria approaches have also been used extensively in energy planning [20,21].

Specifically concerning renewable energy planning techniques at a regional level three main approaches can be identified, namely multi-criteria decision techniques, Delphi techniques and territorial and rural energy planning methods [22]. Multi-criteria decision techniques are able to compare different solutions and in the case of renewable energy are able to evaluate the energy projects not only technically, but socially, economically and environmentally as

well. The most used method of multi-criteria analysis in the energy field has been the Analytical Hierarchy Process, followed by the Elimination and Choice Translating Reality method (ELECTRE) and Preference Ranking Organization method for Enrichment Evaluation (PROMETHEE) [20]. The Delphi techniques are used mainly for planning and forecasting [22]. Finally, participatory approaches have been followed for rural energy planning.

The use of soft computing techniques in EPDSS is rising in recent years [23,24]. Effort has been made in bridging the gap between qualitative and quantitative models through the use of such soft computing techniques [23,25]. Qualitative variables can be expressed through the use of linguistic variables. The linguistic variables in turn can be expressed by fuzzy sets. The quantitative variables can also be expressed by fuzzy sets, with emphasis given to their uncertainty [23]. Fuzzy cognitive maps (FCM) are able to deal with processes like decision making that is based on human reasoning process [26,27]. Because of this, FCMs have been used successfully in different fields. Many applications have been presented in the medical field [28,29], in agricultural applications [30,31], in environmental applications [32] and in energy applications [33,34].

This paper presents the design and implementation of a fuzzy cognitive maps decision support approach for renewable energy sources planning at the regional level (DST). This approach aims to cover the existing gap in the available support systems that are currently available in relation to the end user being a Local Governance officer. Most of the time these officers do not have the background or the need so as to resort in using complicated approaches, software tools and methodologies that are currently available. The presented DST aims to cover this gap by providing the Local Governance Officer with a tool that needs minimum inputs, is straight forward and simple and can provide an overall qualitative estimation promptly. In order to design the DST, at first all the parameters that affect the decision were investigated and are presented. Then for each parameter corresponding indicators were selected. These indicators are in essence the inputs of the DST. An FCM approach was chosen based on its ability to address coherently qualitative and quantitative variables. The FCM, which is the backbone of the approach, is designed and its parameters are set by experts, along with the fuzzification and defuzzification functions. The web-platform that hosts the toolkit is presented afterwards. Finally the DST is validated through evaluation comparisons of the results of the DST and results reached by a panel of experts using real world case studies. Three case studies for the Greek island of Crete are presented in this paper. The scope of DST is to be a useful and modern tool that can be applied in each local community worldwide – after the relevant localization – using as inputs some basic investment data as well as an appropriate list of local and national indicators that can be easily collected based on common statistics and information.

It should be noted that the proposed decision support tool is implemented under the umbrella of the MED funded project “ENERMED—Énergies Renouvelables Méditerranéennes” (Ref. 2419, 01.07.10–30.06.13). In particular, nine regions from six countries (Greece, Italy, France, Spain, Slovenia, Croatia) are participating in the development and pilot implementation of the proposed decision support tool. The tool has been designed from the beginning taking in consideration the needs of the Regions as expressed by them.

2. Materials and methods

The methodology approach followed for the implementation of DST consists of four discrete stages:

Stage A: Parameters investigation. All the parameters that can affect the evaluation of a RES investment are investigated and

presented. The parameters are broken down in five distinct categories; legal/regulatory/administrative, financial, technical, social and environmental. The chosen parameters are the result of interviews with experts, stakeholders and regional officers. *Stage B: Indicators choice.* The parameters that were chosen in Stage A need to be assessed. Relevant indicators are selected from OECD, International Energy Agency, Eurostat and international literature [35].

Stage C: FCM implementation. Based on the results of Stages A and B the FCM used to evaluate the investment is designed and its parameters are set.

Stage D: Implementation of the DST. A web-platform which hosts the DST in the form of a web application is created.

3. Stage A: Parameters identification

3.1. Legal/regulatory/administrative context (P1)

P1.1 License maturity status per RES technology (PV, wind, biomass).

For each RES investment, a number of licenses, permits, contracts, certificates etc. are needed. The type and number has to do with the chosen RES technology, along with the installed size of the investment. The maturity of the investment can be assessed when the difficulty in obtaining each part of the needed paperwork is known.

P1.2 Coherence with national RES policies and binding targets. The examined investments should comply with the RES National Policies, since the local policies are affected by the corresponding National policies. The axes defined in the National Policies can be technology dependent, size depended or even location depended.

P1.3 Coherence with local RES planning.

The investor should always take in consideration the Local RES Planning. The Local Administration sets the approaches concerning the RES planning in its area.

P1.4 Level of bureaucracy in the examined region/investment. The investor should take in consideration that different levels of bureaucracy exist in the different steps of deploying a RES Investment.

3.2. Financial context (P2)

P2.1 Investment appraisal.

Investment appraisal shows the investor the predicted profitability of the investment. It can be performed using many approaches [36–38]. The Net Present Value (NPV), Net Present Cost, Payback Period and Internal Rate of Return (IRR) are the main indicators that can be used in order to evaluate economically an investment. Usually normalized values of these indicators are used (e.g. per installed kW or per kWh produced) in order to facilitate easier comparisons between different possible investment approaches.

P2.2 Funding scheme (e.g. equity, loan, subsidies, etc.).

Funding vehicles/schemes like subsidies, low interest financing, loans etc. can be employed by the investor in order to make the investment more attractive. The higher the funding is the more attractive the investment becomes [38].

3.3. Technical context (P3)

P3.1 RES potential in the specified location per chosen RES technology.

The RES potential in a specified location in most areas of the world has to be taken into consideration when the investor is evaluating RES investments [39]. Solar and wind atlases are used. Also for biomass, it is essential to know the local availability of the quantities needed, so as not to have high transportation costs.

P3.2 Technical applicability.

Technical issues like the maturity of the chosen RES technology, the quality and robustness of the equipment, safety issues etc. should always be assessed by the investor [40]. Also new products that have not been evaluated for longer periods of time can present a high risk.

P3.3 Location constraints.

The distance from the road network is important for the investor, since many times new roads have to be opened [41,42]. Especially for wind parks, the need for new road networks is high. Also it is important to know the distance from the electricity grid (low, medium or high voltage) since new substations will have to be installed in most cases.

3.4. Social context (P4)

P4.1 Social acceptability.

Many concerns rise with big wind park installations or biomass plants [43]. Many urban legends also contribute to hostile stance from the people (scenarios like wind turbines causing sterility to animals etc.). It is a good practice to keep the local communities informed about the future plans and also to educate them in order to minimize false perceptions.

P4.2 Creation of new jobs.

New jobs are created because of RES Investments having to do with the production of the needed materials, the actual installation, the operation and the maintenance of the system [44]. Especially in periods with high unemployment rates, this is a very important factor that has to be considered.

P4.3 Distress factors (e.g. noise/shadowing/odors, etc.).

There are some factors that can objectively cause distress to the local population, because of the operation of a RES investment and should always be considered by the investor [45]. For example, the shadow caused by a slowly rotating 5 MW wind turbine can cause high distress to people living in houses affected by it. Also the noise or the exhaust gases of a biomass plant can have a negative impact on the well-being of local residents.

P4.4 Education impact.

The impact a RES investment can have on education is multi-level [46] and plays an important role to the investor. Visits to the site from school students can affect them in their further studies at the university or technical school by choosing something relevant to renewables. Also the existence of universities located close to the installation might lead to synergies for improvement and upgrades of the systems.

3.5. Environmental context of examined RES investment (P5)

P5.1 Land use (agricultural, forest etc.).

RES are something very important that can add to the sustainability of humankind. On the other hand, though, considerations have to be assessed by the investor before deploying RES investments on land that can be also used for other activities [47]. One major example is that irrigated high fertility agricultural land ought to be used in order to supply humankind with

food and not be filled with photovoltaics or other installations. Also forests can be used in order to supply the needed biomass, but installations in them ought to be discouraged.

P5.2 Effect on wildlife/protected areas.

There are many endangered species on the earth. In order to sustain our environmental heritage certain protected areas have been set [48]. Big installations in these areas ought to be prohibited. Also the proximity of the installation in such an area is important for the investor, since animals and plants do not abide to humanly created border lines on a map. Investments near protected areas should take into consideration special aspects like not cutting mobility routes of animals and so on.

P5.3 Effect on archaeological sites.

The actual installations of big RES investments can be visible from Archaeological sites. This should be avoided.

P5.4. Effect on integrated tourism development areas.

The actual installations of big RES investments can be visible from integrated tourism development areas. This should be avoided.

P5.4. Water needs.

Some RES installations demand a steady supply of water which can be antagonizing other water uses (e.g. irrigation). This applies mainly to biomass plants that use a steam turbine technology approach.

etc. The Qualitative Indicators are based on the expertise of different key actors such:

- Local authorities.
- Potential investors.
- Local industry/SMEs.
- Academic institutions.
- Local communities.
- Environmental groups.

For each of the parameters that were described in the previous section, the relevant indicators were chosen. In some occasions more than one indicator are used for a single parameter. This is implemented because of the significance of the respective parameters. The parameters along with the corresponding indicators are presented in Table 1.

5. Stage C: FCM implementation

5.1. FCM background

As was discussed in the introduction decision support systems can be represented through FCMs. Each aspect of the designed

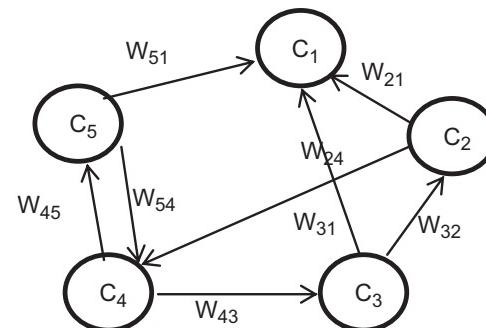


Fig. 1. A fuzzy cognitive map.

4. Stage B: Indicators' choice

The above parameters can provide the basis of the evaluation of RES investments. In order, though, to be able to compare different investments collectively or for specific parameters of it, common ground has to be found. This can be accomplished through the use of relevant indicators. These indicators can provide the framework for direct comparisons between different RES investments.

The parameters are assessed using both of qualitative and quantitative Indicators. The quantitative indicators are based on databases of official statistical sources, GIS systems, maps, legal and administration documents, incentives, programs, procedures,

Table 1
Parameters and relevant indicators.

Parameter category	Parameter	Indicator
P1 Legal/regulatory/administration context	P1.1 License maturity status per RES technology (PV, wind, biomass)	I1.1.1 Process steps
	P1.2 Coherence with national RES policies and binding targets	I1.1.2 Lead time of each of the process steps
	P1.3 Coherence with regional RES planning	I1.2.1 National RES target
P2 Financial context	P1.4 Level of bureaucracy in the examined region/investment	I1.2.2 Renewable primary energy supply
	P2.1 Investment appraisal	I1.3 Compliance with regional planning index
P3 Technical context	P2.2 Funding scheme	I1.4 Lead time
	P3.1 RES potential in the specified location per chosen RES technology	I2.1.1 Purchasing price of produced kW h
	P3.2 Technical applicability	I2.1.2 Cost (€) per produced kW h
P4 Social context	P3.3 Location constraints	I2.1.3 IRR
	P4.1 Social acceptability	I2.2 IRR vs. financing percentage
	P4.2 Creation of new jobs and activities	I3.1 ^{PV} Average daily irradiation for the whole year (kW h/m ² /day)
P5 Environmental context of examined RES investment	P4.3 Distress factors	I3.1 ^{wind} Yearly average wind speed (m/s)
	P4.4 Education – training – skills impact	I3.1 ^{Biomass} Local availability of biomass (qualitatively)
	P5.1 Land use (agricultural, forest etc.)	I3.2 Technology readiness level
	P5.2 Effect on wildlife/protected areas	I3.3.1 Distance from road network
	P5.3 Effect on archaeological sites	I3.3.2 Distance from electrical grid
	P5.4 Effect on integrated tourism development areas	I4.1 Community acceptance
	P5.5 Water needs	I4.2 Created jobs per MW of installed power

Table 2
User inputs.

User input	Description	Values
1.	Size of the installation	10 kW, 100 kW, 1000 kW, etc.
2.	Compliance with regional policies	Very low, low, medium, high, very high
3.	Capital cost (€)	Cost in euros
4.	For PV: Average yearly solar irradiation For wind: Yearly average wind speed (m/s) For biomass: Local availability of biomass	Northern, central or Southern Greece < 5, 5–6, 6–7, 7–8, > 8 Low, medium, high
5.	Distance from grid (m)	< 100, 100–500, 500–1000, 1000–5000, > 5000
6.	Distance from road network	< 100, 100–500, 500–1000, 1000–5000, > 5000
7.	Land use	Urban, agricultural, forest, protected area
8.	Distance from protected areas like Natura (km)	< 1, 1–5, 5–10, 10–50, > 50
9.	Distance from archaeological sites (km)	< 1, 1–5, 5–10, 10–50, > 50
10.	Distance from integrated tourism development areas (km)	< 1, 1–5, 5–10, 10–50, > 50
11.	Funding percentage	10%, 30%, 60%, etc.
12.	Average operating hours per year (only for biomass)	Hours

Table 3
FCM inputs.

FCM input	Description	Values
1.	Number of permits needed	6–10
2.	RES target	Solar: 2200 MW Wind: 7500 MW Biomass: 350 MW
3.	Renewable primary energy supply (RPES)	MW
4.	Compliance with regional policies	Low, medium, high, etc.
5.	Lead time	From data base
6.	Price per kW h	From data base
7.	Cost (€) per kW h	From data base
8.	IRR	From data base
9.	IRR vs. financing percentage	From data base
10.	Qualitative estimation index (e.g. low, medium, high, etc.)	For PV: From average solar irradiation of the area the kW h/m ² /day For wind: From yearly average wind speed For biomass: Low, medium, high, etc.
11.	Technical applicability index	From data base
12.	Distance from road network	Low, medium, high, etc.
13.	Distance from grid	Low, medium, high, etc.
14.	Community acceptance	From data base
15.	Jobs/kW	From data base
16.	Distress index	From data base
17.	Land use	Urban, agricultural, forest, protected area, etc.
18.	Distance from protected areas	Low, medium, high, etc.
19.	Distance from archaeological sites	Low, medium, high, etc.
20.	Distance from integrated tourism development areas	Low, medium, high, etc.
21.	Water use index	Zero, low, medium, high

FCM can be represented through concepts. Each concept is an input, an output, a rule or an intermediate state [49].

$$C_i, \quad i = 1, \dots, N$$

where N is the total number of concepts in the FCM.

The value (A) of each concept is fuzzified in the space $[0,1]$.

$$A_i \in [0, 1], \quad i = 1, \dots, N$$

Concepts are interconnected with arcs that feature different weights (W_{ij}). These weights represent the relationship among concepts. Human knowledge and experience is used in order to decide upon the values of the weights. The weights can express positive, negative or neutral causality and take values in the space $[-1, 1]$.

$$W_{ij} \in [-1, 1], \quad i = 1, \dots, N \quad \text{and} \quad j = 1, \dots, N$$

A simple FCM with 5 concepts is presented in Fig. 1.

The FCM's weights can be represented by a matrix.

$$W_{ij} = \begin{pmatrix} W_{11} & W_{12} & W_{13} & W_{14} & W_{15} \\ W_{21} & W_{22} & W_{23} & W_{24} & W_{25} \\ W_{31} & W_{32} & W_{33} & W_{34} & W_{35} \\ W_{41} & W_{42} & W_{43} & W_{44} & W_{45} \\ W_{51} & W_{52} & W_{53} & W_{54} & W_{55} \end{pmatrix}$$

The matrix for the FCM can be simplified by using zeros where there is no relation between the concepts. The matrix of the FCM presented in Fig. 1 follows.

$$W_{ij} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ W_{21} & 0 & 0 & W_{24} & 0 \\ W_{31} & W_{32} & 0 & 0 & 0 \\ 0 & 0 & W_{43} & 0 & W_{45} \\ W_{51} & 0 & 0 & W_{54} & 0 \end{pmatrix}$$

The influence between the concepts of the FCM is described by Eq. (1) [50]. This equation converges after a number of iterations.

Table 4
Fuzzification procedure.

FCM input	Fuzzification procedure
1.	6 takes the value 0 and 10 the value 1. Linear normalization will take place
2.	350 MW takes the value 0 and 7500 MW the value 1. Linear normalization will take place
3.	The installed power will be divided by the RES target for the corresponding technology
4.	Very low will get the value 1 and very high the value 0. Linear normalization will take place
5.	The least time will take the value 0 the highest the value 1 and normalization will take place
6.	0.087 takes the value 0 and 0.55 the value 1. Linear normalization will take place
7.	0.085 takes the value 0 and 0.11 the value 1. Linear normalization will take place
8.	5% takes the value 0 and 17% the value 1. Linear normalization will take place
9.	The percentage is normalized in the space [0,1]
10.	For PV: 4.5 kW h/m ² /day will be 0 and 5 kW h/m ² /day will take the value 1. Linear Normalization will take place For wind: 0 m/s will take the value 0 and 10 m/s will take the value 1 For biomass: Very low will take the value 0 and very high the value 1. Linear normalization will take place
11.	The value from database
12.	Very low will take the value 0 and very high the value 1. Linear normalization will take place
13.	Very low will take the value 0 and very high the value 1. Linear normalization will take place
14.	Very low will take the value 0 and very high the value 1. Linear normalization will take place
15.	5.8 will be 0 and 45 will take the value 1. Linear normalization will take place
16.	Low will take the value 0 and high the value 1. Linear normalization will take place
17.	The value will take predetermined values Protected area: 1 Urban: 0.9 Forest: 0.7 Agricultural land: 0.6 Industrial: 0
18.	Low will take the value 1 and very high the value 0. Linear normalization will take place
19.	Low will take the value 1 and high the value 0. Linear normalization will take place
20.	Low will take the value 1 and high the value 0. Linear normalization will take place
21.	Zero will take the value 0 and high the value 1. Linear normalization will take place

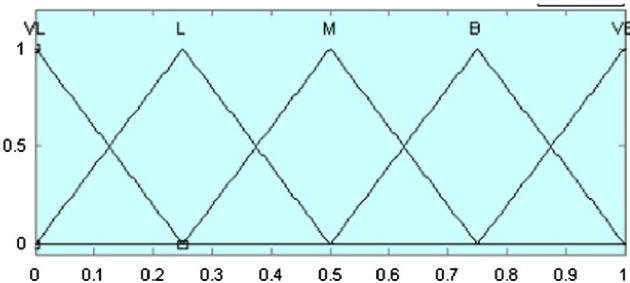


Fig. 2. Membership function for the defuzzification of weights.

This number is affected by the number of concepts and their interconnections.

$$A_i(k+1) = f \left(A_i(k) + \sum_{\substack{j=1 \\ j \neq i}}^n W_{ji} A_j(k) \right), \quad (1)$$

where k is the number of iterations.

Function f in Eq. (1) is the activation function of the FCM. Many functions have been proposed in order to address different situations. These include the sigmoid function, the hyperbolic tangent function, the step function and the threshold linear function. The sigmoid function has been compared to other activation functions of FCM and has been proved to be a useful tool for decisional processes make available to decision-makers [51], as well as in renewable energy management applications [34]. The sigmoid function that is used is presented in Eq. (2).

$$f(x) = \frac{1}{1 + e^{-cx}}, \quad (2)$$

when the steepness parameter is equal to 1, it approximates a linear function [51].

5.2. The FCM of the DST

A five step procedure takes place in the development of the FCM to be used in the DST toolkit.

- Step 1: Definition of the inputs the user has to supply.
- Step 2: Definition of concepts.
- Step 3: Fuzzification of the inputs.
- Step 4: Definition of weights.
- Step 5: Defuzzification of the output.

Depending on the technologies that need to be evaluated the FCM needs to be accordingly modified. In the developed DST three technologies are considered, photovoltaic investments, wind turbine investments and biomass for electricity investments. This was decided because these are the most common RES investments in the Mediterranean region. The decision support system can be easily expanded in the future in order to include more technologies.

Step 1: Definition of the user inputs.

The user inputs that are needed in order to calculate all the relevant Indicators are presented in Table 2. Some extra inputs can be included for the localization of the DST. For example in Greece there are different feed-in tariffs for installations in mainland Greece and on non-interconnected islands.

Step 2: Definition of concepts.

Two types of concepts are going to be used in the proposed FCM; input and output concepts. The output concept will be the overall evaluation. The input concepts are the indicators presented in the previous section. The FCM inputs are in essence the indicators as described in the previous section and are presented in Table 3. The output is concept 22 and is the concept that represents the overall evaluation of the investment. The different concepts are calculated from data

Table 5
FCM weights.

Variable	Experts															Defuzzified value
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
$W_{1,22}$	VB	VB	VB	VB	VB	B	VB	VB	VB	B	VB	VB	VB	VB	VB	-0.97
$W_{2,22}$	VL	VL	L	L	L	VL	L	L	VL	M	VL	VL	L	L	VL	0.15
$W_{3,22}$	L	L	L	M	L	L	VL	L	M	M	L	L	L	L	L	-0.28
$W_{4,22}$	B	M	M	B	M	M	B	B	M	M	B	M	M	M	B	0.62
$W_{5,22}$	VB	VB	VB	VB	VB	B	VB	VB	VB	B	VB	VB	VB	VB	VB	-0.97
$W_{6,22}$	M	B	VB	VB	M	VB	VB	VB	B	VB	M	VB	VB	VB	B	0.85
$W_{7,22}$	VB	VB	VB	VB	VB	B	VB	VB	VB	B	VB	VB	VB	VB	VB	-0.97
$W_{8,22}$	B	VB	VB	B	VB	B	VB	VB	VB	B	VB	B	B	VB	VB	0.88
$W_{9,22}$	M	B	B	M	B	B	M	M	M	B	B	B	M	B	M	0.63
$W_{10,22}$	L	VL	L	M	L	M	VL	VL	L	M	M	L	L	VL	M	0.27
$W_{11,22}$	M	M	B	B	VB	L	M	M	M	B	B	B	M	B	B	0.63
$W_{12,22}$	B	B	B	B	B	B	M	B	B	VB	M	M	B	B	B	-0.72
$W_{13,22}$	B	B	B	B	B	VB	B	B	M	B	B	B	M	B	B	-0.73
$W_{14,22}$	VB	L	M	B	L	M	M	M	B	VB	B	L	M	L	B	0.57
$W_{15,22}$	M	VL	M	VB	L	M	L	VB	B	L	B	VB	L	M	M	0.53
$W_{16,22}$	M	L	M	B	M	M	L	M	B	L	B	B	L	B	B	-0.53
$W_{17,22}$	M	M	L	B	B	M	L	M	B	M	L	M	L	B	M	-0.50
$W_{18,22}$	VL	B	M	VB	L	VB	M	L	VL	M	B	B	L	VB	VL	-0.50
$W_{19,22}$	L	M	B	VB	L	B	L	B	VB	B	L	B	M	VL	M	-0.55
$W_{20,22}$	VL	L	M	L	VL	M	L	VL	M	L	L	M	L	VL	L	-0.25
$W_{21,22}$	L	M	B	VB	VB	B	B	M	M	VB	B	M	B	M	M	-0.67
$W_{2,3}$	B	M	M	B	M	B	L	M	B	M	B	M	VB	B	M	-0.62
$W_{6,7}$	M	M	M	M	L	M	M	M	M	M	B	M	M	M	M	-0.50
$W_{7,6}$	B	M	B	M	M	B	B	M	L	B	M	B	B	B	M	0.62
$W_{8,9}$	M	M	B	M	M	B	B	M	B	M	M	B	B	M	M	0.60
$W_{9,8}$	L	L	L	L	VL	L	M	L	L	L	L	L	M	M	L	0.28
$W_{15,14}$	VB	B	VB	VB	VB	B	VB	VB	VB	B	B	VB	VB	VB	VB	0.93
$W_{18,1}$	M	L	B	L	M	B	M	B	M	B	L	M	M	L	L	-0.48
$W_{19,1}$	B	VB	B	VB	VB	B	B	VB	B	VB	B	M	B	B	VB	-0.83
$W_{20,1}$	L	M	M	L	M	M	B	B	B	B	M	M	L	L	L	-0.47

Where VL: Very low; L: Low; M: Medium; VB: Very big; B: Big.

available in a data base using the user supplied inputs. The data base is compiled by data found in relevant laws, simulation software packages etc.

Step 3: Fuzzification of the FCM inputs.

The fuzzification of the inputs takes place as is described in [Table 4](#). It is essentially a mapping of quantitative and qualitative variables in the space [0,1].

Step 4: Definition of the FCM weights.

The definition of weights is carried out according to the methodology presented in [\[34\]](#). A questionnaire had been prepared and distributed among 15 experts of this field. The experts answered the questions using linguistic variables. The experts included the authors of this paper, experts from the ENERMED project partners and experts from academia, who all have considerable experience in the field of RES. These values are then defuzzified in the space [0,1]. Using the centroid defuzzification method the linguistic values are transformed in numerical values using the membership function presented in [Fig. 2](#). The weights are presented in [Table 5](#).

[Fig. 3](#) presents the FCM with all the interrelations as drawn from the questionnaires.

Using the information provided in [Table 5](#) the W_{ij} matrix that was described in [Section 5.1](#) can be formed. By using this matrix with Eqs. [\(1\)](#) and [\(2\)](#) of [Section 5.1](#), using a c parameter for Eq. [\(2\)](#) equal to 1, the output can be calculated.

Step 5: Defuzzification of the output.

The output Concept will have a value in the space [0,1], as was described in the theoretical background of [Section 5.1](#). This output is defuzzified qualitatively (poor, average, good, very

good) so as to express how valuable the Investment appears to be. The defuzzification membership function is presented in [Fig. 4](#) as was defined by the experts.

6. Stage D: The web platform hosting the DST

6.1. General information about the web-platform

The toolkit is hosted on a website that runs the dynamic content management platform INCOM CMS [\[52\]](#). It uses php for the creation, management, maintenance and publishing of content on a webpage. Its versatile character allows the creation of numerous web based applications like portals, eshops, etc. It is based on open architecture and is very user friendly. It uses MySQL for its database management.

The toolkit was developed initially in a Fortran environment where it was tested and optimized. Then a new custom plugin was created for the INCOM CMS in order to become a web application. The plugin is based on HTML 5, CSS3 [\[53\]](#), php and ajax.

The toolkit is hosted at <http://enermed.cres.gr>. Currently it is available in the English and Greek languages and is programmed for use in Greece. The platform allows more languages and localizations. More localizations are currently planned to be implemented in the near future. The use of the DST is free. During its development, the DST has been presented in 3 workshops focused on local governance and renewables development where the input from the target users was taken into consideration and the DST was accordingly optimized.

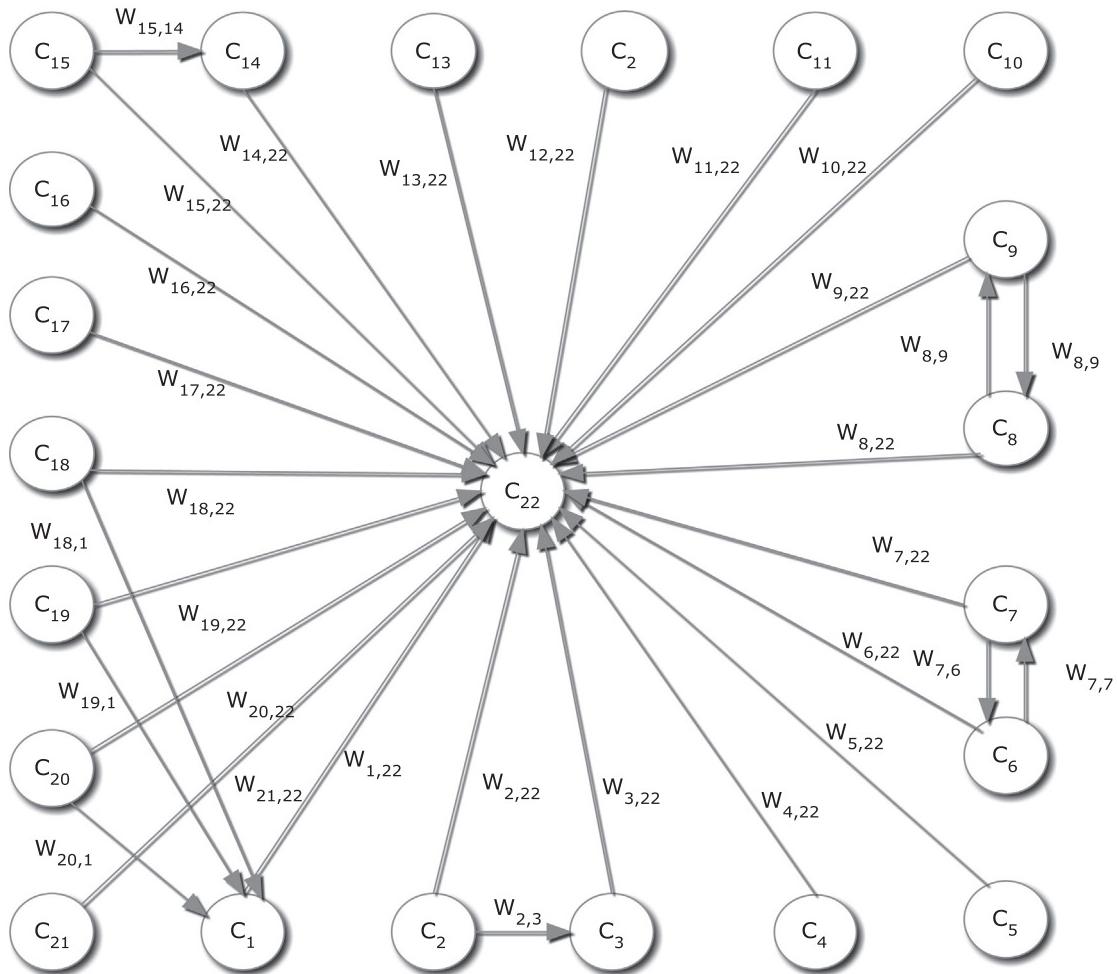


Fig. 3. Fuzzy cognitive map of DST.

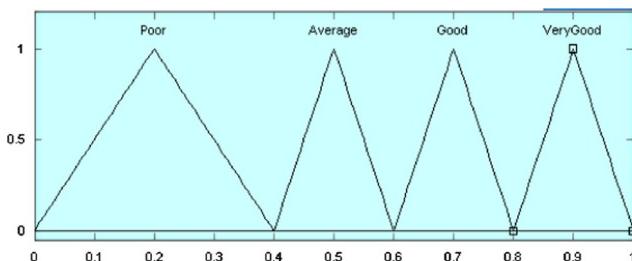


Fig. 4. Membership function for the defuzzification of the overall evaluation.

6.2. A typical user session

The website which hosts the toolkit also hosts background and supporting content concerning RES. The user by selecting the DS Tool menu and the relevant country faces the technology selection page which is presented in Fig. 5.

From there the user chooses among wind energy, biomass and photovoltaics. On this first page a set of ON/OFF criteria are presented. According to the legal framework in each country it is possible that some investments at specific locations are simply not allowed. Thus a set of ON/OFF criteria is evaluated for each investment before going forward with the overall investment evaluation. If these minimum constraints as described by the ON/OFF criteria are not met, then the evaluation will terminate informing the user that the investment is legally not feasible. If no such conditions apply the user is presented with the web-page

where the data of the investment under evaluation is submitted. This web-page is presented in Fig. 6. With the data given by the user and the data that is pre-programmed in the data base of the toolkit the evaluation of the investment is possible.

The results are supplied as presented in Fig. 7.

The main results include the overall qualitative investment evaluation, the payback period without taking into account any funding mechanisms, the relevant feed-in tariff, the new jobs that are expected to be created in the total design, production, installation and operation cycle of the technology because of the investment and the saved CO₂-e emissions per year using data of the relevant country. The user can download a small report of these results in a pdf file as well.

Finally there is the option to see advanced results of the evaluation. There a graphical representation of the qualitative impact various parameters have on the overall outcome of the investment evaluation is presented. Through this the user can understand better which parameters or combination of parameters affect the investment evaluation and look into differences of investments that present the same overall evaluation. This is presented in Fig. 8. The bars for which longer corresponds to better have different color than the ones for which shorter corresponds to better.

7. DST application and validation

The DST was validated through evaluation comparisons of the results of the DST and results reached by a panel of experts using

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Fig. 5. Technology selection webpage.

real world case studies. Three case studies for the Greek island of Crete are presented in this paper. Crete island (Greece) is blessed with high solar, wind and biomass potential. The local communities were chosen because one partner of ENERMED project is the Energy Agency of Crete, which was created by the Region of Crete and there is also a debate going on among the people of the island on whether to support few big RES installations or many with lower installed power. The developed DSS can enable the local officers to be able to perform a preliminary assessment of any investment plan with ease.

The collection of data was implemented with the aid of the Energy Agency of Crete. These real case studies were evaluated by experts and the DST, without the experts knowing the results of the DST. The results of the DST and the experts are provided below, along with a comparison.

Case Study 1: Application in a wind park.

The location of this wind park investment is at Agios Kyrrilos, Crete. The input data of the DST along with the corresponding results are presented in **Table 6**. The overall investment evaluation is poor. This was also the verdict of the experts' panel which evaluated this investment as poor, mainly because the wind potential is relatively low in comparison with other areas of Crete island, the site is located at a protected area in a forest and it is far from the grid.

Case Study 2: Application in a PV park.

The location of this pv park investment is Mesoxorio, Crete. The input data of the DST along with the corresponding results are presented in **Table 7**. The overall investment evaluation is good. The experts' panel reached the same conclusion since it is an investment with average to good impact in all aspect



The screenshot shows the 'enermed' website interface. At the top, there is a logo for 'enermed Mediterranean Renewable Energies' with a sun icon. A navigation bar includes links for 'Home', 'DS Tool' (which is highlighted in green), 'How The Tool Works', 'About Res', and 'Contact'. To the right of the navigation bar are icons for the United Kingdom and Greece flags.

The main content area features a large photograph of a solar panel array installed in a grassy field under a clear sky. Below the photograph, there are three tabs: 'Wind Energy' (green), 'Biomass' (light blue), and 'Photovoltaics' (dark red). A note below the tabs reads: "At the checkboxes please check if any of the below conditions apply for the investment under evaluation. If nothing applies just press the 'SUBMIT' button."

The form consists of several input fields:

- Name: (Latin letters without spacing)
- Size of the installation (kW):
- Compliance with regional policies: Very Low
- Capital Cost (€): (with a small circular icon)
- Location of the installation: Northern Gre
- Distance from grid (m): <100
- Distance from road network (m): <100
- Land Use: Forest
- Distance from protected areas like Natura (km): <1
- Distance from Archaeological Sites (km): <1
- Distance from Integrated Tourism Development Areas (km): <1
- Is the installation going to take place on an autonomous island?: Yes
- Funding Percentage (%):

A 'Submit' button is located at the bottom left of the form area.

At the very bottom of the page, there is a footer with the text: "© 01/01/2013 | All rights reserved" and links for "Site by evanem", "Incom-oms", and "web promotion".

Fig. 6. User inputs webpage.

The screenshot shows the ENERMED Decision Support Tool (DST) interface. At the top, there's a logo for "enermed Mediterranean Renewable Energies" and language selection buttons for English and Greek. Below the header is a navigation bar with links to "Home", "DS Tool" (which is highlighted in green), "How The Tool Works", "About Res", and "Contact". The main content area features a large image of a solar panel array against a blue sky with white clouds and sunbeams. A red rectangular box highlights a specific area on the right side of the panels, labeled "Markup Area". Below this image are three buttons: "Wind Energy" (green), "Biomass" (light green), and "Photovoltaics" (purple, which is the active tab). The page then displays several lines of text with horizontal lines separating them, providing detailed evaluation results for a PV test:

- The overall investment evaluation is: **Very good**
- The payback period for this investment without taking into account any funding mechanisms is **7 years**.
- The feed-in tariff for the investment under evaluation is: **0.18 €/kWh**.
- For the evaluated investment **4.70** jobs are expected to be created in the total production, installation and operation cycle.
- The investment under evaluation is saving **141.5 tn** of CO₂-e emissions per year.

[\[Click here for Advanced Results\]](#)

You can download your personalized evaluation [here](#). (Right click and save target if you want to keep it)

At the bottom of the page, there are copyright and footer links:

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Fig. 7. Results webpage.

categories, but cannot be considered very good due to the high payback period and the location of the investment (in a forest, near a Natura area).

Case Study 3: Application in a biomass plant.

This biomass plant is located in Heraklion, Crete. The input data of the DST along with the corresponding results are presented in [Table 8](#). The overall investment evaluation is good. The experts' panel considered this investment also as a good investment as it scores well on all indicators that are evaluated for such an investment.

8. Discussion

Engaging regions in action under the new climate change regime and fostering citizens to adopt sustainable energy patterns, remains still a challenge. A new impetus for commitment was put in place for local regions, through the Covenant of Mayors (CoM) initiative by the EU communities. The key challenge is the

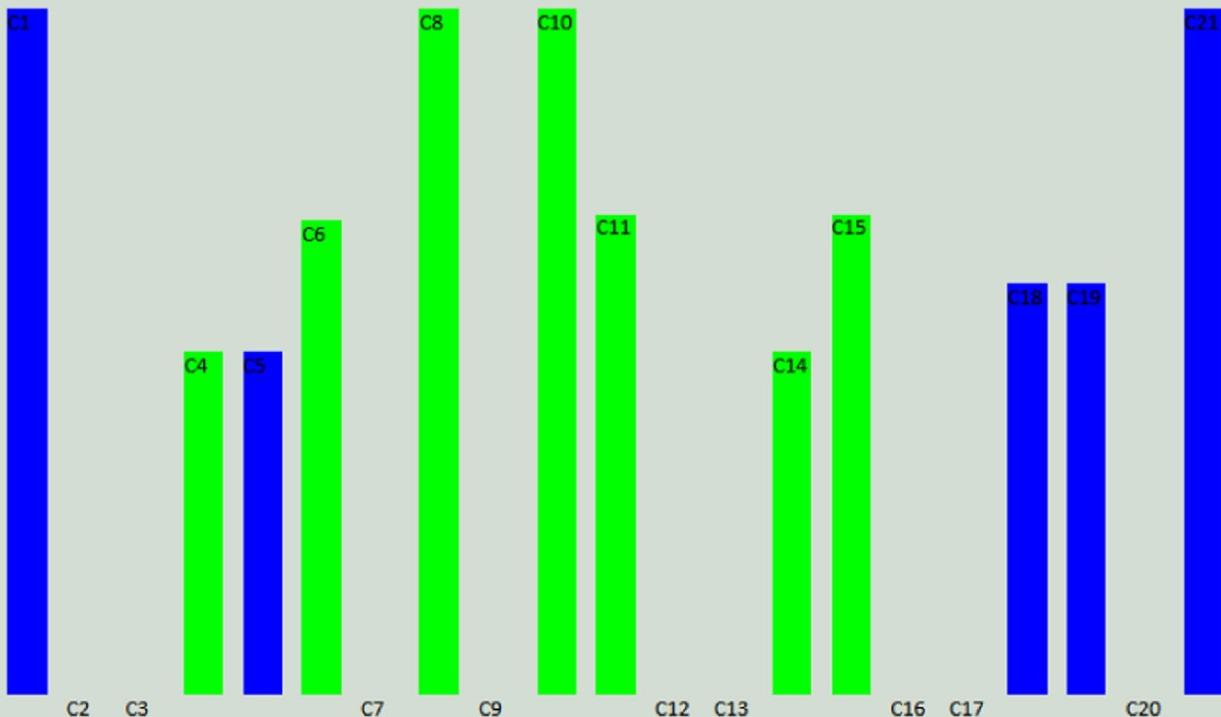
penetration of RE, since most rural communities have vast unexploited RES potential (solar, wind, biomass, etc.).

The presented decision making tool could really contribute towards the preparation of sound regional, intra-regional and cross-border strategic and operational policies for Renewable Energy Sources as a driving force for sustainable development. The output of the tool can play an important part in the formation and monitoring of the relevant policies until 2020. It can be a tool for cooperation and minimization of the common difficulties which are faced by regions in their effort to form and implement RES policies and investments, taking in consideration the economic crisis. As a result, the regions will have the option to investigate an appropriate number of possible RES projects in each location. The outputs of the tool can support the full preparation and submission of appropriate and reasonable proposals for funding in the “new” available funding mechanisms (ELENA, JESSICA, etc.).

The DST was improved through discussions held with the Region partners of the ENERMED project and the participation in 3 workshops during the development of the DST. The DST was

[Click here for Advanced Results]

Below you can find a graphical representation of the qualitative impact various parameters have on the overall outcome of the investment evaluation. Through these the user can understand better which parameters or combination of parameters affect the investment evaluation and look into differences of investments that present the same overall evaluation.



C1 corresponds to the number of permits needed. (Shorter bar is better)

C2 corresponds to how high the national RES target for this technology is compared to the rest of RES technologies. (Longer bar is better)

C3 corresponds to the current technology primary energy supply. (Longer bar is better)

C4 corresponds to the compliance with regional policies. (Longer bar is better)

C5 corresponds to the lead time. (Shorter bar is better)

C6 corresponds to the feed-in tariff. (Longer bar is better)

C7 corresponds to the power production cost. (Longer bar is better)

C8 corresponds to the payback period. (Longer bar is better)

C9 corresponds to how high the available funding is. (Longer bar is better)

C10 corresponds to the RES potential. (Longer bar is better)

C11 corresponds to the technical applicability. (Longer bar is better)

C12 corresponds to the distance from road network. (Shorter bar is better)

C13 corresponds to the distance from the electrical grid. (Shorter bar is better)

C14 corresponds to the community acceptance. (Longer bar is better)

C15 corresponds to the number of the created new jobs. (Longer bar is better)

C16 corresponds to the distress index. (Shorter bar is better)

C17 corresponds to the land use. (Shorter bar is better)

C18 corresponds to the distance from protected areas. (Shorter bar is better)

C19 corresponds to the distance from archaeological sites. (Shorter bar is better)

C20 corresponds to the distance from integrated tourism areas. (Shorter bar is better)

C21 corresponds to the water use of the investment. (Shorter bar is better)

You can download your personalized evaluation here. (Right click and save target if you want to keep it)

Fig. 8. Advanced results webpage.

validated, in the end, using a number of real world case studies and comparisons with results obtained by a panel of experts.

Finally, one of the most important innovations of this toolkit is that is implemented in a web application that is available free of charge on the internet.

9. Conclusions

Summarizing, the DST has the following advantages:

- Possibility to perform an integrated evaluation of a RES investment in local communities, in exceptionally less time than the

time needed without the use of an information system like the DST.

- Possibility for the user to choose the detail of information and results to be accessed. The website is rich in information including considerable background and supporting data concerning RES. The user can decide on the level of detail of the results that are presented from the DST.
- Possibility to be applied in each local community worldwide, after the relevant localization, using as inputs some basic investment data as well as an appropriate list of local and national indicators that can be easily collected based on readily available statistics and information.

Table 6
Case study 1—Agios Kyrilos.

	Case 1—wind park investment
User input	
Size of the installation	7200 kW
Compliance with regional policies	Medium
Capital cost	9000,000 €
Yearly average wind speed	5–6 m/s
Distance from grid	> 5000 m
Distance from road network	100–500 m
Land use	Forest
Distance from protected areas like Natura	< 1 km
Distance from archaeological sites	5–10 km
Distance from integrated tourism development areas	> 50 km
The installation is going to take place on an autonomous island	No
Funding percentage	0%
Output	
Overall investment evaluation	Poor
The payback period for this investment without taking into account any funding mechanisms	8 years
The feed-in tariff for the investment under evaluation	0.08785 €/kW h
New jobs creation in the total production, installation and operation cycle	98.28
Saved CO ₂ -e per year	21,072.096 t

Table 7
Case study 2—Mesoxorio.

	Case 2—PV park investment
User input	
Size of the installation	170 kW
Compliance with regional policies	Medium
Capital cost	221,000 €
Location of the installation	Southern Greece
Distance from grid	500–1000 m
Distance from road network	100–500 m
Land use	Forest
Distance from protected areas like Natura	1–5 km
Distance from archaeological sites	10–50 km
Distance from integrated tourism development areas	> 50 km
The installation is going to take place on an autonomous island	No
Funding percentage	0%
Output	
Overall investment evaluation	Good
The payback period for this investment without taking into account any funding mechanisms	10 years
The feed-in tariff for the investment under evaluation	0.18 €/kW h
New jobs creation in the total production, installation and operation cycle	7.99
Saved CO ₂ -e per year	250.172 t

Table 8
Case study 3—Heraklion.

	Case 3—biomass plant investment
User input	
Size of the installation	190 kW
Compliance with regional policies	Medium
Capital cost	344,000 €
Local availability of biomass: high	High
Distance from grid	< 100 m
Distance from road network	< 100 m
Land use	Industrial area
Distance from protected areas like Natura	5–10 km
Distance from archaeological sites	5–10 km
Distance from integrated tourism development areas	> 50 km
Average operating hours per year	6816
The installation is going to take place on an autonomous island	No
Funding percentage	0%
Output	
Overall investment evaluation	Good
The payback period for this investment without taking into account any funding mechanisms	2 years
The feed-in tariff for the investment under evaluation	0.2 €/kW h
New jobs creation in the total production, installation and operation cycle	1.10
Saved CO ₂ -e per year	1508.7216 t

Therefore, the information decision support systems, such as the one presented in this paper, can aid the evaluation of a RES investment in a consistent way, can assist local policy making and support a modern RES environment in local communities. The theory, framework and overall approach of the presented DST can be used for developing new decision support systems aimed at different end users (e.g. investors) by choosing different parameters and indicators that are better suited for that specific application.

The developed approach is straight forward to the final user, needing only few input data from his part. The DST was validated through evaluation comparisons of the results of the DST and results reached by a panel of experts using real world case studies. Finally it is available free of charge on the internet.

Future work includes the localization of the toolkit for various EU and worldwide countries and the inclusion of more RES technologies.

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